

EXO BIOLOGY STUDY

Analytical Systems for Biological Study of Mars

The role of electron microscopy and electron optical
techniques in Exobiology

by

Humberto Fernández-Morán
Department of Biophysics
University of Chicago

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Introduction

Within the framework of the stated problems relating to the diagnosis of the presence of life on Mars and its characterization, we shall try to discuss the possible contributions of electron microscopy and related electron optical techniques, centering on experiments in situ, with telemetry back to Earth. Essentially, this approach is based on the fundamental role of microscopy in its broadest sense as a central unifying discipline of the Natural Sciences, which has immeasurably augmented man's dimensional span in the scale of living systems. It represents a logical complement and extension of the comprehensive automatic light microscope system for use on a planet as proposed by J. Lederberg and his associates (1).

Electron microscopy extends the range of resolution of the light microscope several hundredfold, scanning the whole range of submicroscopic structures down to the molecular and atomic level. Beyond this, electron microscopy and related techniques possess certain inherent specific advantages and capabilities which are uniquely suited to the space environment and to Exobiology studies in general.

The nature of life is literally writ small, in the submicroscopic domain, and electron microscopy permits us to read directly all variants of the sculpture of living forms at the molecular level. Thus, within Lederberg's (2) comprehensive evolutionary scheme of Chemogeny, Biogeny, and Cognogeny, an electron optical scan would ideally supplement the chemical scan and radiation probes to

automatically integrate relevant information pertaining to life at the various hierarchical levels of subcellular, viral, macromolecular, and molecular organization. In this quest the electron microscope, and the microscope in its broadest sense, may prove to be the prime analytical tool both for the detection of "entropy pockets" in an alien planetary environment, and for subsequent operational inter-action and controlled modification of this domain. Since the fundamental definition of Biogeny is the well-ordered, information carrying macromolecule, electron microscopy appears to be one of the most promising direct approaches to its detection. In this connection, detection of any type of ordered macromolecules or their derivatives--which can only be accomplished directly by electron optical techniques--would provide invaluable information relevant to the origin of life and giving clues to its cognogenic, biogenic or chemogenic origin. As Lederberg (1) has pointed out, we can reasonably expect to find evidence of microscopic life in any "drop of water," "pinch of soil," or "gust of wind." All the more reason to suppose that extension of this microbiological analysis by electron microscopy through the macromolecular domain may well prove to be the most reliable diagnosis for the presence of life on Mars or any planet. Imagine, for example, how much we would miss today if electron microscopy had not disclosed the sophisticated morphology of virus particles (bacteriophages, etc.) in which, quite literally, resides the combined information on their structure and function. In turn, how much would we not miss if our analytical scan of the environment on Mars were not to encompass the whole spectrum of submicroscopic organized forms which may well prove to be particularly well represented under the peculiar ambient conditions of Mars.

From these considerations stem the basic concepts of miniaturized and mobile electron microscope "stations" embodying appropriately miniaturized componentries for an integrated collection and transport of specimens, physico-chemical and physical processing of the samples remotely controlled by servo systems and coupled with a vidicon-transmitter telemetry chain. Such a miniaturized electron microscope station would not only serve as a powerful analytical tool for detection of life on Mars, but also for exobiological

studies in general.

Methodologically, electron microscopy and related electron optical techniques have the significant advantage of being able to extract the maximum of information from samples which are several orders of magnitude smaller than those required for light microscopy. This economy or optimized parsimony of the ratio of information output referred to submicroscopic sample size is of critical importance when dealing with automated exobiological experiments in situ which have to be relayed back to earth by telemetry. In many ways, one can invoke a revealing example quoted by Lederberg when pointing out (1,2) the extremely cumbersome automatic instrumentation that would be needed to catch a hare and then to determine its nutritional requirements. By analogy, one could point out that a systematic electron optical survey can be carried out on an ultrathin section only 100Å in thickness and not more than a few square microns area, which is several orders of magnitude smaller than the requisite light microscopy samples of several hundred thousands Å thickness and scores of square microns in area. This is particularly relevant to the problem of being able to sample not only the atmosphere and surface of Mars, but perhaps more importantly, the subsurface and deeper strata of Martian soil, where we may expect to find the most valuable clues on the evolution of life. An electron microscope equipped with a miniaturized ultra-microtome equipped with a diamond knife (3,4,5) or a diamond drill for production of ultrathin sections which can be read off directly with the attached electron microscope would serve all of these required functions in a practical and efficient way. As will be described later on, these systems would not in any way replace, but in fact ideally supplement, the present contemplated light microscope systems.

In the following, a brief outline will be given of the distinctive methodological features of electron microscopy in terms of the relative interest that this approach should attract in dealing with the basic problems. Only the essential engineering details will be presented of the specific project embodying a miniaturized electron microscope with coupled preparative devices for sampling, preparing, sorting, and telemetering of specimen data. Finally, some of the promising approaches in the development

and implementation of these proposals will be surveyed, with particular emphasis on the priority assigned to this project which merits a determined effort.

Miniaturized Electron Microscope--Vidicon systems with automated specimen collection, preparation, sampling and telemetered data output for Exobiology studies.

Methodologically, electron microscopy and related electron optical techniques are of unique operational value as major tools for Exobiology and space investigations in general because:

(a) The requisite conditions for electron microscopy--high vacuum, electron-beam and ion irradiation, thin specimens (100-1,000 Å), and low-temperature electron microscopy and electron diffraction, are very similar to conditions encountered in outer space and planetary environments.

(b) Successful application of the high spatial resolution of the order of 6 to 8 Å reproducibly attainable with modern electron microscopes, now permits direct visualization of structural organization down to the molecular level, and in favorable cases of the array of atoms in crystalline lattices. In fact, this unique possibility of obtaining data, which is directly related to a limited number of atoms or molecules only, and is thus well above the level of statistical uncertainty commonly associated with indirect analytical methods, is of particular importance in the study of the structure and composition of submicroscopic particles, such as those of interstellar matter with diameters of a few tenths of a micron down to 10 to 100 Å. Moreover, electron optical and related microprobe analytical techniques are at present the only adequate methods for examination of gaseous and solid components as they occur in the extremely high dispersion, ultrahigh vacuum and low temperatures encountered in outer space, and in certain planetary environments.

(c) The special techniques that have been developed for electron microscope studies of specimens are actually readily adaptable to examination of extraterrestrial matter, because we are dealing essentially with the same problems. Thus, the use of thin graphite or single-crystal, stable coherent films, of plastic films, replication, shadow-casting, etc. are suitable for these purposes. In

this way, and despite the numerous unsolved technical problems, it should be possible to obtain and examine, as well as perform chemical analysis (electron microprobe analysis, electron diffraction, correlated physico-chemical and mass-spectrometric analysis, etc.) of material from space, lunar and planetary probes in a way that cannot be achieved by any other known technique. It should be pointed out that most of the relevant fine structures of the specimen materials would be well below the resolving power of present light and x-ray microscopes.

(d) Electron microscopy and related electron optical devices are essentially extensions of television techniques. They can, therefore, be readily adapted directly to TV cameras such as those used on Surveyor or Ranger space craft adapted for use in the exploration of Mars. A television survey camera essentially contains the same basic elements (electron source, electro-magnetic focusing lenses, vidicon tubes, etc.) as an electron microscope. It would only be necessary to add certain components in order to convert such a television survey camera into a simple type of electron microscope which would considerably extend the range of resolution of such a camera from the present meter range to the sub-micron range. In fact, the proposed use of miniaturized electron microscopes represents a logical supplement and extension of the "Vidicon Microscopes" for planetary exploration as suggested by Dr. Joshua Lederberg of Stanford University, and now being developed in Dr. Gerald Soffen's laboratory at the Jet Propulsion Laboratory in the California Institute of Technology (7). Even a simple miniaturized electron microscope (coupled directly and preferably in the same vacuum system with the television survey camera) would have a resolving power of the order of a few hundred Angstrom units, which is well below the useful resolving power (of about 3,000 to 2,000 Å) of the best light microscopes presently available. Moreover, instead of using a vidicon tube which works on a photoconductive principle, the electron image of such an electron microscope can be converted directly by suitable image intensifiers (6) into electrical signals, which when highly amplified and converted to a frequency-modulated signal can be sent and received on Earth. Alternatively, as discussed further on, the electron microscope

image could be recorded directly on special high-resolution and ultrathin photographic emulsions, suitably demagnified by a factor of several thousand times. In this highly condensed form the electron microscope image could be either read out and telemetered back to Earth, or conceivably sent back directly in suitably packaged form for retrieval on Earth (see supplement to this report).

It is of course possible and actually advisable to combine the automatic light microscope system proposed by Lederberg and his associates with this type of miniaturized electron microscope system, in order to achieve a mutually supplementary, step-wise analytical processing of the samples. In many ways both systems complement each other and can be used either combined or singly in appropriately designed planetary missions.

Although all present commercial electron microscopes are considerably larger, weighing over a ton with attached power supply cabinets, it is considered feasible to substantially reduce the size and weight of microscopes with advanced techniques. Thus, by appropriate scaling down of the lenses, including the possible use of permanent magnet lenses which do not require a separate lens power supply, it should be possible to reduce the column to about 1 foot length or perhaps even less; and to combine this with appropriately miniaturized high-voltage pointed filament electron sources and controlled power supplies. It should be pointed out that there have already been several successful attempts to produce commercially small, extremely compact electron microscopes, such as the RCA type EMT permanent-magnet electron microscope. This small table-model microscope designed by Reisner and Dornfeld (8) has permanent magnet lenses and attains a resolution of about 100 Å. Electron microscope lenses have a very small useful numerical aperture (of the order of 100th radian), and their depth of field is therefore extremely large compared with that of light microscopes of high resolution where the numerical aperture is large (1 to 1.6). This large depth of field of electron microscopes is of particular interest because it makes possible the recording of "stereoscopic" views of objects having considerable extent in the axial direction. This would also considerably facilitate recording of sharp images by remotely controlled servo systems.

General design features of a simple miniaturized electron microscope:

The schematic diagram (Figure 1) illustrates some of the general design features which can be incorporated into a miniaturized electron microscope for detection of extra-terrestrial life. The microscope column (with a length of 6 to 12 inches approximately) comprises a pointed filament source (of tungsten, or preferably rhenium for longer life) with a Schottky type of gun for T-F emission at accelerating voltages of 10 to 50 kV. One objective lens either of the permanent magnet type, or of the standard electro-magnetic, or electro-static or superconducting lens type is shown here. However, it may be necessary to use an objective and projector gap in series to obtain higher magnifications. The image is recorded either directly onto a vidicon tube with fluorescent screen, or on image intensifier of the solid state type or of the scanned type (6). Alternatively, the special type of ultrathin photographic films on tapes could be used for recording of the image either at high magnification or after appropriate demagnification. The whole column assembly can be made very rigid and attached directly onto the television survey camera, or as a supplementary element to the vidicon microscopes currently being designed at the Jet Propulsion Laboratory.

At present, two basic approaches are being pursued in trying to solve the difficult specimen mounting and preparation problems: (a) There is a possibility of effecting a continuous scan of ultrathin specimens (fine particles in aerosol suspensions, atmosphere samples, etc.) by sandwiching between vacuum-tight (200 to 1,000 Å thickness) single-crystal mica, graphite, aluminum or beryllium windows. These windows would be transparent to electrons, and in this case, the microscope itself would be constantly kept under high vacuum which does not have to be broken in order to examine the specimens. This would also permit a continuous sampling of wet or partially hydrated specimens, and the use of very fine "ultratape" reels of indefinite length.

The envisaged miniature objective pole pieces with a bore of 1mm or less would be ideal for this approach. In the rarefied atmosphere of Mars this type of specimen examination approach may prove to be particularly useful. A variant would involve the use of an impaction plate (like in the case of the vidicon microscope

being designed in Dr. Soffen's laboratory) (7) which can be periodically cleaned by suitable electrostatic filtering devices.

(b) Specimens collected on a traveling ultrathin ribbon of tantalum or rhenium foil about 100 to 1,000 Å in thickness and about 1 mm wide with appropriate reinforcements with suitably etched slits or holes (1 to 20 microns in diameter). These thin metal tapes can be fed automatically into the microscope after having been exposed to the environment, in the same way as the transparent tape first proposed by Lederberg et al (1) or by the Gulliver Biochemical Probe device being developed by Dr. Norman H. Horowitz of California Institute of Technology and by Dr. Gilbert V. Levin of Haselton Laboratories, Inc. (7). The advantage of these rhenium or tantalum foils would be that no direct specimen substrate film is required, and that they can be re-used many times by appropriate heating to destroy old specimens. This practice of heating to incandescence in a vacuum has proven to be very effective to eliminate contamination. The "ultratapes" would be mounted on shields which can be operated by remotely controlled servo systems. A similar type of reel could also act as a substrate for the ultrathin, very fine-grained photographic emulsions used in recording electron microscope micro-images as described later.

The miniaturized electron microscope would be equipped with an appropriately miniaturized ultramicrotome (e.g. of the Fernández-Morán type with "V-shaped diamond of sapphire bearings without lubrication" equipped with a diamond knife (5) for automatic production of ultrathin sections of the specimens which would be automatically fed to the microtape specimen reel and examined directly by electron microscopy. It is also interesting to consider the possibility of using a similar device to produce an "aerosol" of very fine particles, by using a diamond knife revolving at high speeds, of even the hardest materials. These particles could then be examined in the previously described impact device. Alternatively, a miniaturized diamond drill with a servo-controlled motor would be used to prepare samples of the different strata of Martian soil. All of these specimen preparation devices would automatically convert the sample into appropriate ultrathin sections or fragmented specimens suitable for electron microscopy. In analogy with the

ingenious design first proposed by Lederberg et al (1), one could combine ultrathin sectioning and ultrasonic dissociation of the specimens with a suitable centrifugal or ultracentrifugal separator. It should be possible to miniaturize these separators to permit use of density gradient techniques which would be of key value in sampling the environment and in obtaining specimens of the size range of virus particles and larger macromolecules (DNA, nucleoproteins, etc.). The required high ultracentrifugal forces could perhaps be generated by a modified design of the Beams magnetic suspension ultracentrifuges suitably scaled down for this purpose.

In its simplest form, such a miniaturized electron microscope should not be more difficult to operate than are any of the other contemplated devices for detection of extraterrestrial life. Since all of its components are of rugged construction, and readily adapt to the already tested television cameras for space craft, these devices can be expected to perform reliably, without the need for sophisticated techniques. This point deserves particular emphasis, since it is generally accepted that high resolution electron microscopy does indeed require considerable sophistication and experience in experimental technique. Here we would not be dealing with high resolution electron microscopy, but rather with electron microscopy in an intermediate range of resolution which could yield a vast fund a useful information which is well beyond the limits of light microscopy. Moreover, this type of electron microscope can serve as a prototype for the special demagnification electron microscope to be described in a supplement to this report to be used for condensing information on ultrathin films for subsequent retrieval.

Design features of more advanced miniaturized high resolution electron microscopes:

With present advances in the generation of stable superconducting electro-magnetic fields, low-temperature electron microscopy, etc. it is conceivable that the contemplated design of new types of high resolution (cryo-electron microscopes) immersed in a liquid helium cryostat using superconducting electro-magnetic lenses (3,4,5,9) and related types of miniaturized electron microscope systems may find direct application in the examination in situ of

lunar and planetary matter by electron optical techniques.

In view of the already available high vacuum and low-temperature in outer space, such a cryo-electron microscope could be miniaturized. By being of smaller size and invested with a far greater resolving power with useful magnifications of the order of 10^5 to 10^6 times, than a light microscope, it would permit a greater range of applications, and thus supplement and extend the presently contemplated automatic light microscope systems for use on a planet as proposed by Lederberg and associates.

By further development of the concepts embodied in our earlier low-temperature electron microscopy techniques (3,4) it has been possible to design a new type of miniaturized high resolution electron microscope totally immersed in liquid helium. These "cryoelectron microscopes" operating at temperatures of 1 to 4° Kelvin would embody the following significant features:

- (a) Highly stable superconducting electro-magnetic lenses, with very ripple-free magnetic fields of persistent current in the optimum case;
- (b) Operation in ultrahigh vacuum and low temperatures resulting in decisive advantages of minimized specimen contamination, specimen damage and thermal noise;
- (c) Improved single-crystal pointed filament sources, with optimum conditions for both low voltage (k.e., 1 to 10 kV) and high voltage electron microscopy. In addition, the use of high efficiency viewing (single-crystal fluorescent screens, fiber optics, etc.) and recording devices operating at optimum low temperatures would make it possible to use high speed cinematography and stroboscopic recording (e.g. obtained through pulsed T-F emission from pointed filament sources) for attainment of high temporal resolution combined with high spatial resolution.

The described combination of optimized instrumental design parameters operative under conditions of minimized specimen perturbation represents one of the most promising coherent experimental approaches towards attainment of the theoretical resolution limit (about 2 \AA) in direct examination of organic and biological structures. At present an instrument of the type shown in the enclosed figure is being developed at our laboratories in the University of Chicago,

as part of a comprehensive research program in the field of low-temperature electron microscopy (9).

Potential applications of electron microscopy in combination with other techniques for the detection of extraterrestrial life:

Based on the extensive background of classical terrestrial biological observations, both with the light and electron microscopes, the direct observation of structural detail at the various levels of dimensional hierarchies lends considerable support to the morphological approach. While it is likely that certain structural attributes may be specific expressions of life, it is recognized that many other criteria derived from biochemistry, physical chemistry, and the physical sciences, are in fact, indispensable to characterize biogenic origin.

With this in mind, it is interesting to note that an electron microscope can be readily used in combination with other techniques to carry out correlated biochemical and biophysical studies. Thus, by introducing certain modifications in the design of the described miniaturized electron microscope, the following powerful analytical techniques can be implemented:

- (a) X-Ray microscopy (11) particularly in the use of microabsorption x-ray spectrometry;
- (b) X-Ray microdiffraction which would be of particular use in examining larger bulk samples of fossil or other material. This could lead to the detection of the characteristic small-angle, x-ray diffraction pattern, for example, of collagen and other fibrous proteins which appeared to be uniquely specific for biogenic origin.
- (c) Different types of scanning microscopes (Nixon, Westinghouse) (6) which would be of particular operational value in the Martian rarefied atmosphere, since they could permit the use of microprobe analysis outside of the microscope itself.

Other conceivable applications would be in connection with mass spectrometry, micro-spectrophotometry, micro-histochemistry, micro-fluorometry, radio-isotope biochemical probes, and devices like the Wolf trap of Professor Wolf Vishniac for detecting the growth of micro-organisms. This latter combination is of particular significance in connection with the detection of submicroscopic

organisms, like viruses which may be potentially dangerous to man. It is, for example, conceivable that single-cell cultures could be kept frozen in special microchambers, then infected or otherwise placed in contact with extraterrestrial material and the subsequent changes in the thawed-out cell observed both by light and electron microscopy as well as by biochemical techniques. In fact, the Wolf trap optics lend themselves readily to adaptation for electron optical techniques.

All of these analytical systems complement each other and should be used in combined form in appropriately designed planetary missions. Electron microscopy is particularly suitable for the study of certain features of biological systems when adequately supplemented by the results of parallel biophysical and biochemical investigations. One of the most challenging problems that can be approached with electron microscopy in combination with x-ray diffraction techniques, would be the detection in Mars of the presence of highly organized repetitive, periodic but asymmetric fibrous and other anisodiametric structures at the macromolecular level. These have been hitherto found on earth to be characteristic of life, although admittedly no single criterion is acceptable. Thus, for example, the repeating pattern of 660 Å observed in collagen both by x-ray diffraction and electron microscopy has been found to hold true even for fossil specimens. Such patterns are not explicable solely by a statistical combination of random asymmetric elements, but imply at least some form of replication, self-assembly and self-checking, which are quite distinct from the epitaxial growth of crystals. Although much work remains to be done in this area, it remains a fundamental problem to ascertain what morphological criteria at a given level of morphological organization are characteristic of biogenic origin.

Once a given type of specimen has been thoroughly worked out and understood, it would be possible to program these microscope systems to "react" specifically to a given submicroscopic entity of predetermined configuration. This latter possibility would be of special interest in case of "electron microscope sensor and contamination monitoring devices." The merits of this approach are manifest when taking into consideration the example already

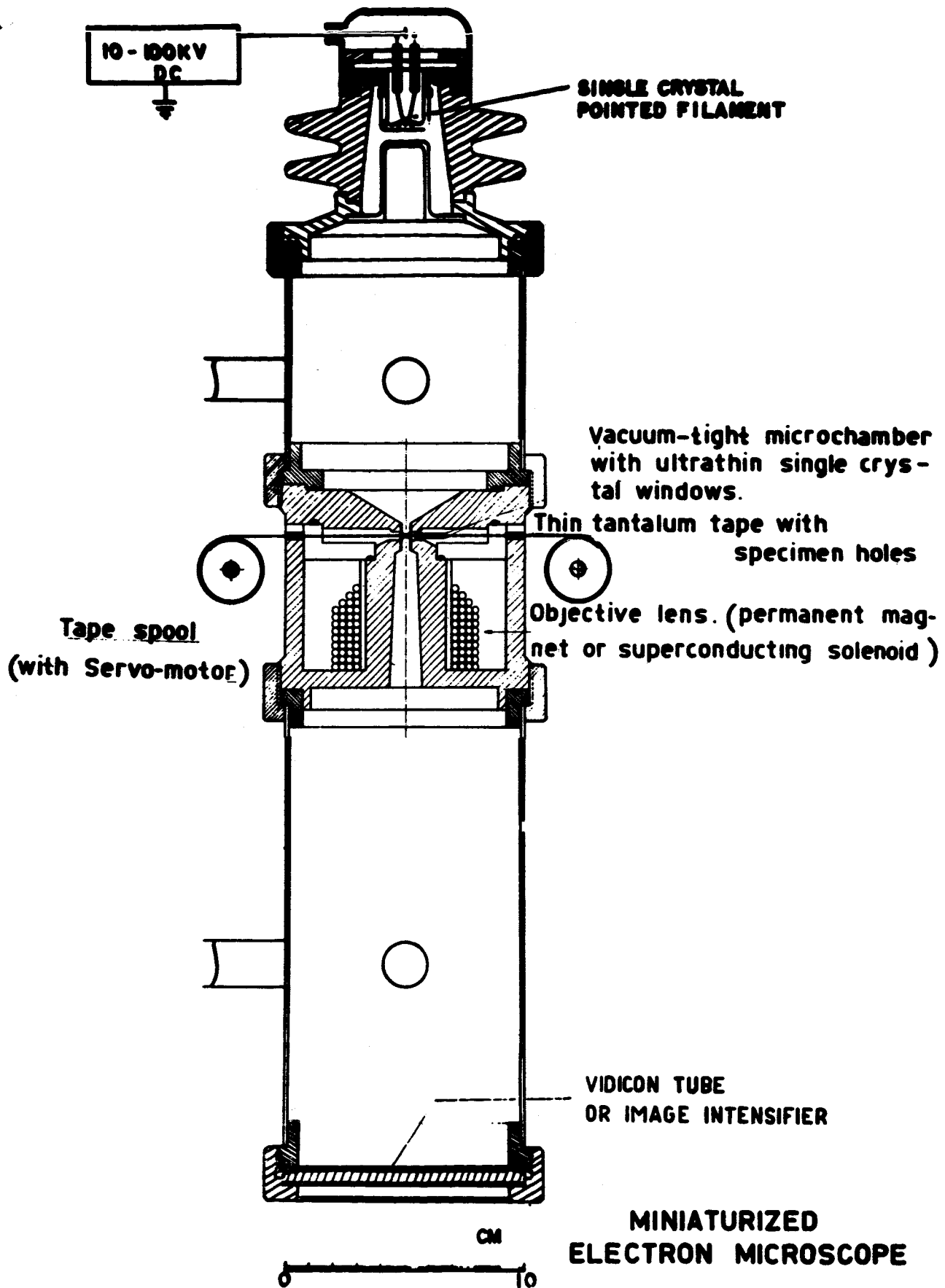
discussed by Lederberg (2): assuming capture of a dust sample of about 100 milligrams, containing at most 100 micrograms of organic matter, perhaps 1 μ g (about 10 nanomoles) of a particular species. Appropriate diffusion, differential ultracentrifugation techniques, etc. could be devised to separate such species and the various steps monitored by light microscopy until the enriched molecular species can be examined directly by electron microscopy. In the envisaged science of metrology, the orderly study of methods of measurement, (2) the described electron microscopy and electron optical techniques are bound to play a key operational role. Implementation of the described experimental approaches appears to be well within the present capabilities of technology and applied scientific research.

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TEXT OF ILLUSTRATION

Figure 1: Schematic Diagram of miniaturized electron microscope
for Exobiology Studies.



**MINIATURIZED
ELECTRON MICROSCOPE**

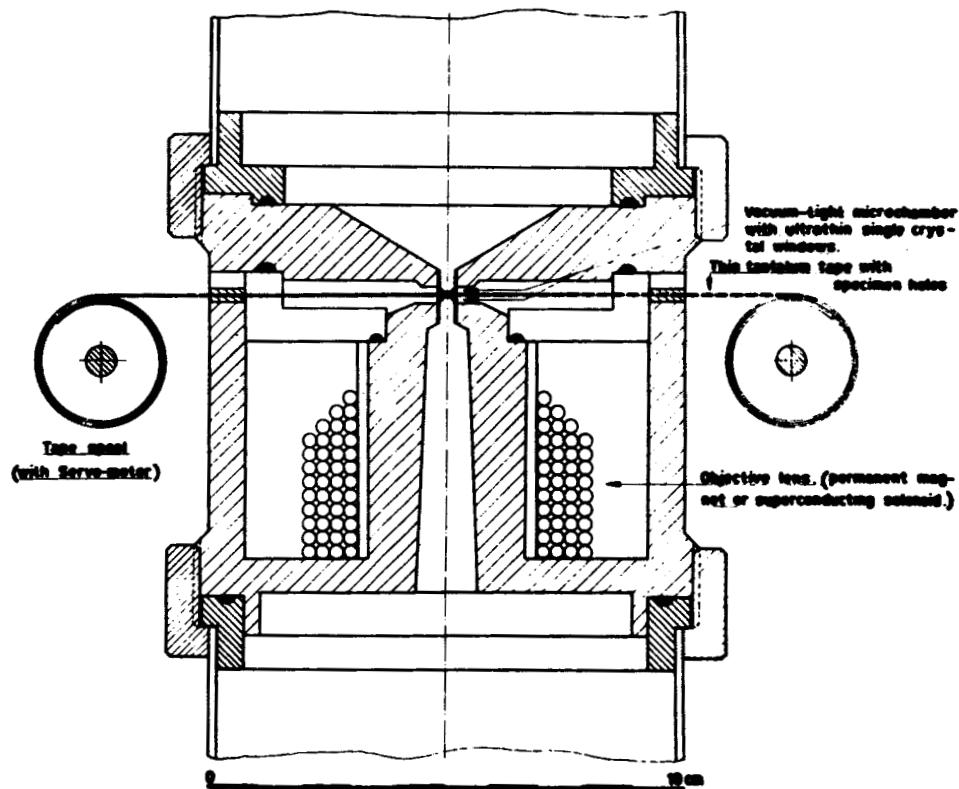


Figure 1b: Schematic Diagram of Objective Pole Piece of Miniaturized Electron Microscope. Showing Vacuum-Tight Microchamber with Ultrathin Single-Crystal Windows Transparent to Electrons, and Thin Tantalum Tape with Specimen Holes.

EXOBIOLOGY STUDY

ANALYTIC SYSTEMS FOR THE BIOLOGICAL STUDY OF MARS:
THE ROLE OF ELECTRON MICROSCOPY AND ELECTRON OPTICAL
TECHNIQUES IN EXOBIOLOGY.

Potential Use of Electron Microscopy for Ultra-Miniaturized
Information Storage and Retrieval with Electron Optical
Demagnification, Combined with Direct Retrieval of Recorded
Microtape to Supplement Telemetry in Exobiology.

The basic problem limiting the information retrieval envisaged from Mars or any other planetary mission seems to be the limit to the bits of information obtainable, of the order of about 10^9 bits of information, which is given by inherent telemetry parameters. There is also a long time interval involved. These limitations impose severe restrictions in the design of any type of system for the detection of extraterrestrial life.

It is therefore suggested that the development of a miniature microscope may also be of critical importance from the point of view of information condensation and retrieval. It has been demonstrated that the electron microscope cannot only be used to magnify but also to faithfully demagnify images several thousandfold (2, 6). In our case, we used a commercial electron microscope (Siemens Elmiskop) with a pointed filament source to produce very small microbeams of 100 to 1,000 Å diameter to write and print out letter and diagrams which were only a few microns to a few hundred Å in size (Fig. 2). This printing was done on specially developed ultrafine grain films of silver halide (silver iodide and silver bromide with crystallites of the order of 100 Å; film thickness about 100-200 Å). Möllenstedt achieved the same results by a more complicated device involving modifications induced in a plastic film which were subsequently brought out by shadow casting. (Fig. 3). This means that one could record any type of information from letters to diagrams to oscilloscope signals, etc., in such a way that, in the optimal case, the contents of several million volumes of books can be condensed on an area of a single page

size or its equivalent. Therefore, this miniature microscope approach appears to be, in general, applicable to the whole problem of information collection, storage, and retrieval which is a critical bottleneck in extraterrestrial studies.

Specifically, it is proposed that all of the information obtained during the Mars missions and other extraterrestrial missions be considerably condensed by electron optical demagnification (ratio of demagnification, 1:1,000 to 1:50,000 or more). This would mean that bits of information, greater in number by several orders of magnitude, can be imprinted directly onto reels of special ultrathin tape by demagnification electron microscopy. The ultrathin tape of silver halide is about 100-200 Å thick and can be mounted on suitable resistant thin tapes of rhenium, tantalum, or other refractory material. The amount of information that could be recorded in a tape reel with a total area the size of a type-written page varies from the content of a 1,000,000 volume library (each volume, 500 pages) to approximately a 10,000,000 volume library. A roll of this ultramicrotape after recording would be wound onto a bobbin of only a few cubic centimeters at most. This bobbin could be detached and provided with its own jet propulsion (plasma or other type of propulsion that is practical and longlived for such a small object) and with a radio beacon or other device to indicate and monitor its presence and trajectory. This "space courier pigeon" (in analogy to the earlier uses of microfilm transmission by pigeon courier post) would be programmed to "home", back to earth, by making use of optimized navigational techniques. Once within the reach of our earth or retrieval capabilities in outer space, these microtape capsules could be directly retrieved and read-out in space. This is of particular importance in view of the possible contamination danger. Also, attempts to bring back the capsule would probably involve prohibitively large devices to prevent its burning up upon reentry. It is realized that the problem of retrieval is complex. However, many of these capsules could be sent, or many copies of the first one made immediately and distributed to enlarge the margin of retrievability through redundancy.

The problem of demagnification of the image could be approached

in several possible ways:

- (a) Either the vidicon image can be made to scan directly, using electron microbeams and electron optical demagnification through a permanently attached miniaturized electron microscope, operating in reverse, so as to print directly on the very fine photographic film which would be slowly unrolled from the tapes. It should be noted that from our experience, extending over more than five years, once printed, these silver halide films, which are of the direct print-out type and need no further development or fixation, are very stable to radiation and preserve detail of the order of about 100 Å quite clearly. This type of recording a television image onto an area only a few square microns in size would be ideal since the direct television image, with a larger number of bits than can be presently obtained, then can be read-out back on earth or on space platforms with a converted electron microscope and image intensifier;
- (b) The alternative would be to use the principle of advanced electron beam recording techniques such as those developed at General Electric by Newberry (1) or some other type of ultraoscilloscope recording, not only for vidicon recording but for recording of all other types of information.

A critical analysis of this admittedly rather speculative proposal reveals that the main operational problem would be one of retrieval. It remains to be demonstrated that it is feasible that an object only a few cubic inches or a few cubic feet at most, if provided with sufficiently compact power supply and navigational aids, can navigate back to earth with some measure of reliability. It might be asked whether it could escape first order perturbation influences on the way and be literally led "astray." Even if it approached earth and could make a rendezvous with a space platform or with a large type of satellite, can the mechanism of read-out function reliably enough that it can be automated? Many of these questions are outside of the domain of our present experience, but it is perhaps conceivable that by the time this concept is ready to be applied, we will be far enough advanced in our space technology to have space platforms which are manned. Under these conditions, retrieval of the space pigeon (alternative name:

"Minicomp" or Minicompo system) becomes much more practical.

Actually, the main problem here resolves itself into the basic question, "Is the expected gain in information storage and retrieval worth the whole effort?" Here, the answer is undoubtedly "Yes". First of all, there is no telemetry device that could conceivably carry this amount of information (of the order of 10^{15} to 10^{20} bits) and provide truly significant data retrieval with a sufficiently high signal to noise ratio in an economical and reliable fashion, as the described micro-recorded image. Even if manned space flights to Mars become feasible, the use of information packages of this type is just as necessary as in today's communication network. No amount of teletype, telephone, or even television, can replace the letter, the book, drawings, pictures, blueprints, etc.

This problem will become even more acute as the distances to other planets and surrounding perturbations (magnetic field, sunspots, etc.) make direct electro-magnetic radio communications very long or actually impossible. Sooner or later, we will have to develop some type of a compact, condensed, ultra-miniaturized information storage and retrieval system. It will also be one of the safest ways of sampling alien environments with a minimum of cross-contamination, since a great deal of information can be recorded and transmitted without effecting actual bodily contact.

It should be noted that development of this idea on earth is already of key significance in order to cope with the critical problem of information condensation and retrieval under the conditions of the present "information explosion" in the published bibliography. With all of these considerations in mind, it is suggested that this type of approach be given serious consideration and assigned a reasonably high priority since it merits a determined and concerted effort.

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TEXT OF ILLUSTRATIONS

Figure 2: Electron micrograph of ultraminiaturized circuit patterns produced by photoengraving with electron microbeam probes (500 to 1,000 Å diameter) on special ultrafine photographic film. X 10,000.

Figure 3: Miniaturized letters (of less than 1 micron) engraved on thin collodion film using electron microbeam probes produced by demagnification in an electron microscope (G. Möllenstedt and R. Speidel, Physik. Bl. (16, 192, 1960). X 20,000.

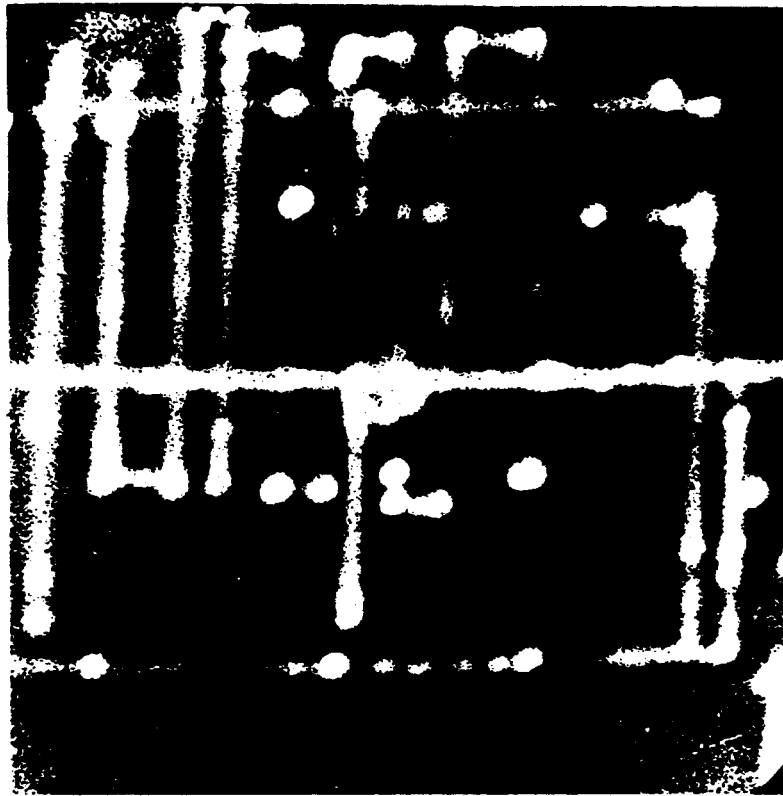


Fig. 2: ELECTRON MICROGRAPH OF ULTRAMINIATURIZED CIRCUIT PATTERNS PRODUCED BY PHOTOENGRAVING WITH ELECTRON MICROBEAM PROBES (500 to 1000 Å diameter) ON SPECIAL ULTRAFINE PHOTOGRAPHIC FILM. X 10,000.



Fig. 3: MINIATURIZED LETTERS (of less than 1 micron) ENGRAVED ON THIN COLLODION FILM USING ELECTRON MICROBEAM PROBES PRODUCED BY DEMAGNIFICATION IN AN ELECTRON MICROSCOPE. (G. Möllenstedt and R. Speidel, Physik. Bl. 16, 192, 1960)